PARAMETRIC AND EXPERIMENTAL INVESTIGATION OF THE EDFEG

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Abstract

The objective of this effort was to investigate both parametrically and experimentally the properties of the Explosive Driven Ferroelectric Generator (EDFEG). The parametric investigation was conducted using a simulation developed by the Institute of Electromagnetic Research (see paper P1-E31) and the experimental investigation using the explosive test facilities at Texas Tech University (see paper XXX). Both efforts were conducted synergistically in order to fully understand the characteristics of the EDFEG and to optimize its operation. Results of both studies will be presented.

1. INTRODUCTION

Operation of the EDFEG is based on shock depolarization of an electrically polarized ferroelectric material [1 – 4]. The working material considered in these studies is lead zirconium titanate (PZT). Other materials will be considered in future experiments, since this impacts the output of the generator. In addition to the type of ferroelectric material used, other factors that affect the operation of the EDFEG include the geometry and dimensions of the module, the electric breakdown threshold of the material, the electrical conductivity and permittivity of the material under shocked and unshocked conditions, pressure in the shock front, detonation velocity of the high explosive (HE), and whether the HE directly acts on the material or is used to accelerate a flyer plate to generate the shock wave in the module. The objectives of this effort are to parametrically and experimentally investigate the impact of each on the operation of the EDFEG.

A. Shock Initiation in the Module and Factors Influencing the Process

The basic factors, which influence the energy output of EDFEG devices, include shock wave characteristics, characteristics of the ferroelectric material after shock compression, load resistance, electrical breakdown, and geometrical dimensions of the module. Unfortunately, a consistent theoretical treatment that addresses the processes by which the polarized domains in the ferroelectric materials reorient during the action of a shock wave is still

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14. ABSTRACT
The objective of this effort was to investigate both parametrically and experimentally the properties of the Explosive Driven Ferroelectric Generator (EDFEG). The parametric investigation was conducted using a simulation developed by the Institute of Electromagnetic Research (see paper P1-E31) and the experimental investigation using the explosive test facilities at Texas Tech University (see paper XXX). Both efforts were conducted synergistically in order to fully understand the characteristics of the EDFEG and to optimize its operation. Results of both studies will be presented.

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a challenging problem. Consequently, the previously mentioned parameters can be subdivided into three groups.

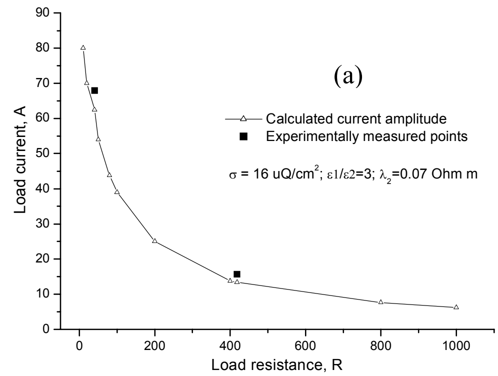
The first group of parameters includes those, which can be relatively easily accounted for through experiments and empirical models, thus forming the basis for parametric study. This group includes the load resistance and the geometrical dimensions of the module.

The second group includes those parameters, which can only be accounted for indirectly by adjusting their values in numerical phenomenological models by fitting the calculated results to the experimental results. These parameters include the permittivity and conductivity of the compressed PZT material. This group also includes those parameters whose maximum possible value can only be measured experimentally; i.e., spontaneous polarization of the ferroelectric material, which can be measured by performing gradual depolarization of the ferroelectric material. It should be noted here that the product of the spontaneous polarization of the PZT material and the area of an element of the surface represents the main factor which determines the amount of charge released to the active load during the depolarization process.

The third group includes the parameters, which can be accounted for only from experimental results. These parameters include electrical breakdown strength of the compressed material and shock wave characteristics. The shock wave, propagating through the PZT ceramic powder, has very complex characteristics, and generally speaking, this wave represents the superposition of a number of elastic and inelastic acoustic and shock waves. This wave pattern strongly depends on the initial pressure generated at the surface of the PZT module by either a flyer plate or direct action of HE. It is currently believed that pressures which generate only elastic waves is the most beneficial for the normal operation of the EDFEG, since, when chaotically disorientating the domain structure, they do not cause massive injection of free carriers and related effects, which could lead to bulk electrical breakdown and an increase in the bulk leak conductance in the shock-compressed portion of the ferroelectric material.

B. Parametric Study Results

One of the most easily adjusted parameters, which can facilitate maximizing the output of the EDFEG, is the load resistance. A parametric study of this parameter was conducted by using both the experimental results generated by TTU and a phenomenological computer code, addressing EDFEG operation, designed at IEMR. Experimentally and numerically generated parametric plots of the amplitude of the current and of the energy density in the active load are presented in the Fig.1. These plots were derived for the shock depolarization of a PZT disk with a length of 2.5 mm and a diameter of 25 mm.



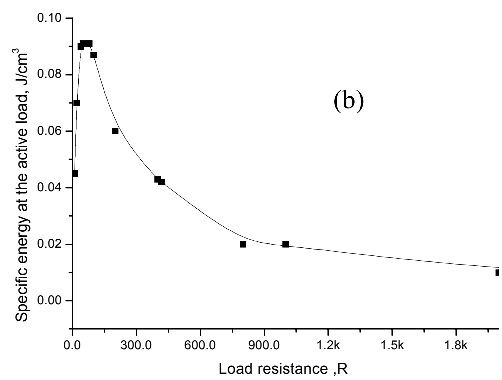


Fig. 1. Calculated and experimentally measured (a) current amplitude and (b) specific energy in the active load as a function of load resistance

As can be seen in the above plots, the current in the active load decreases as the active load resistance increases. The reason for this phenomenon is the increase in losses in the shock-compressed potion of the PZT module due to bulk-leaks stimulated by the shock wave. The theoretical and experimental results suggest that the EDFEG can be effectively treated as a current source until the load resistance begins to approach the shunt resistance of the shock-compressed portion of PZT the module. The plot for the specific energy density indicates that this value passes through a maximum at a certain resistance, which indicates an optimal balance from the energetic standpoint between the generated current and the current loss through the shock-compressed portion of the PZT module.

These results also establish that the primary source of current in the load is due to depolarization of ferroelectric material and not the direct piezoelectric effect. The amount charge passing through the active load that is generated by the direct piezoelectric effect is governed by the relationship:

$$Q = d_{33}SP$$

where d_{33} is the piezomodule of PZT, S is the surface area of the end of the module, and P is the upper limit of the pressure in the shock wave, which turns out to be an order of magnitude less than that produced in the experiments.

The second important factor, which influences energy and current output of the EDFEG, is geometric size and shape. In this publication, only disk-shaped PZT modules, having different lengths, will be considered, since only these shapes were tested by TTU. Plots of the amplitude of the current and the energy density in the active load as a function of PZT module length for a fixed load resistance is presented in Fig.2.

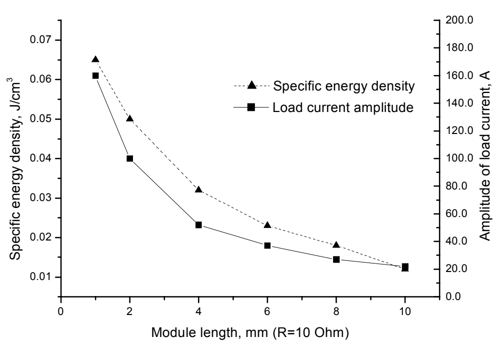


Fig. 2. Calculated current amplitude and specific energy in the active load as a function of PZT module length for load resistance R=10 Ohms.

As it can be seen in Fig. 2., short modules are optimal from the standpoint of generating higher currents and higher energy densities in active loads. These results are physically sound since the surface charge density depends only on the bulk density of polarization dipoles and not the volume of the PZT module. However, the experiments show that the limiting factors for short modules are bulk electrical breakdown in the compressed portion of the PZT module and bulk current leaks, which is addressed in more detail in [1].

One of the very important, but as of yet unaddressed, factors, that influences the operation of the EDFEG, is the characteristic of the shock wave traveling through the PZT module. There are two ways to initiate the shock wave within the module. The first is through direct action of the HE on the module and the second is to use the HE to accelerate a flyer plate that impacts on the module. As seen in Fig. 3, the flyer plate method generates higher voltages than the direct action method. This may be due to uniform excitation of the shock wave by the flyer plate, which may not be possible with direct action excitation. It has been shown in [1,2] that the rise and fall time of the shock wave upon entering and exiting the module, respectively, varies linearly with the relaxation time. If the shock wave enters the module at an angle, this could impact the relaxation time. The effect of the relaxation time and initiation technique on the output voltage is shown in Fig. 3.

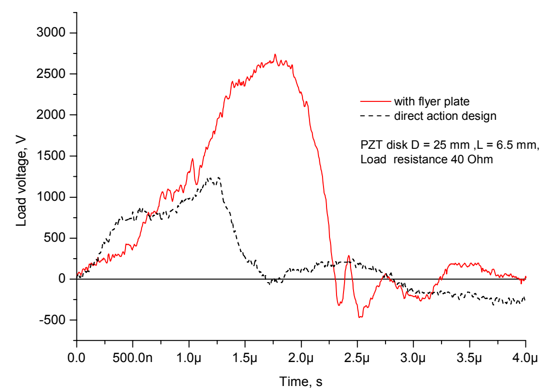


Fig.3. Waveforms of pulses generated in PZT disks for flyer plate and direct action versions of the EDFEG. Both modules are loaded with a 40 Ohms load.

III. Conclusion

These experimental investigations and numerical studies clearly demonstrate that the output characteristics of the EDFEG is a very complex balance of "positive" characteristics, such as spontaneous polarization of the PZT material, small length of the sample, and large surface area, and "negative" characteristics, such as diminishing electrical breakdown strength, intensified by diminishing permittivity in the shock-compressed portion of the PZT, and bulk leaks, which are believed to become worse as the pressure in the shock wave increases beyond a certain limit.

IV. References

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